Truly, there are lies, brazen lies, and statistics, but let’s not, my friends, forget the psychology!

Reliable Decoding of Neural Data

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Goal of Neuroscience

The task of neural science is to explain behavior in terms of the activities of the brain

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Means of Investigation

*The task of neural science is to explain behavior in terms of the activities of the brain*

*Eric Kandel, Principles of Neural science, 4th ed., 2000*

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Brain Activity</th>
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<tbody>
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<td>Response time</td>
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Behavior

Response time
Accuracy
...

Brain Activity

Extracellular Recordings
Electroencephalography (EEG)
Magnetoencephalography (MEG)
Functional Magnetic Resonance Imaging (fMRI)
...

Behavior $\Rightarrow$ Neural Activity
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Research Question $\rightarrow$ Experiment Design $\rightarrow$ Stimuli $\rightarrow$ Neural Processing and Encoding
Goals

Localization
- Early visual perception
- Object recognition
- Motor response

Information flow
- Attention
- Executive control
- Inhibition

Neural Processing and Encoding
SPM via GLM
SPM via GLM
Limitations

- Carry no validity testing (not cross-validated)
- Are mass-univariate
- Do not care about cross-trial variance
- Account neither for not-controlled sources of variance, nor covariance/causal structure
- Rely on restrictive assumptions (forward EEG/MEG/BOLD model)
- Obliterate the information through averaging and/or spatial smoothing
Limitations

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- Account neither for not-controlled sources of variance, nor covariance/causal structure
- Rely on restrictive assumptions (forward EEG/MEG/BOLD model)
- Obliterate the information through averaging and/or spatial smoothing
- Are behavior-based models ignorant of the brain structure
- Are confirmatory approaches dragged into solving exploratory problems
Known Organization of the Visual System

Van Essen et al. (1992)
Model of the Visual System

Serre et al. (2007)
From Blobology to Models

GLM

Models
From Blobology to Models

Haxby et al. (2001)
From Blobology to Models

Haxby et al. (2001)
Decoding Approach: Reverse the Flow!

GLM -> Decoder

Research Question -> Experiment Design -> Stimuli

Information Integration Models

Neural Processing and Encoding
Decoding Approach: Analysis
Decoding Approach...

- Is data modality neutral
- Could incorporate the models of the brain functioning
- Is driven by the data, not by the assumptions
- Is capable of per-trial analysis
- Provides validity testing (cross-validation)
- Accounts for various sources of variance and covariance/causal structure (Sato et al., 2008)
- Relaxes modeling assumptions of the signals
Decoding Approach...

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- Relaxes modeling assumptions of the signals
- Provide super-acuity effect (Kamitani & Tong, 2005)
The task of neural science is to explain behavior in terms of the activities of the brain


Behavior

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Accuracy

Brain Activity

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Extracellular Recordings

Temporal Resolution: High
Spatial Resolution: None
Invasive: Yes
Direct Measurement: Yes

Brain Activity

Extracellular Recordings
Electroencephalography (EEG)
Magnetoencephalography (MEG)
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...
Extracellular Recordings

Experiment

- Auditory experiment (Thanks Dr. A. Luczak, Dr. K.D. Harris)
  - Five pure tones (3, 7, 12, 20, 30 kHz)
  - Five different natural sounds
- Animal research: rat
- Eight four-site recording shanks
- 105 units (neurons)

Goal

- Confirm relevance of the recorded neural population to auditory processing
- Assess relevance of each neuron toward processing of specific auditory stimulus
EEG/MEG

**Brain Activity**

**Extracellular Recordings**
- **Electroencephalography (EEG)**
- **Magnitoencephalography (MEG)**

**Functional Magnetic Resonance Imaging (fMRI)**

**Temporal Resolution:** High
**Spatial Resolution:** Low
**Invasive:** No
**Direct Measurement:** Yes
EEG

Experiment

▶ Cognitive modality: visual processing
▶ Data from Fründ et al. (2008)
▶ Experimental task: meaningful vs “object-like”
▶ Analysis task: colored vs line-art
▶ 852 trials
▶ 140 time samples per trial, 31 EEG electrode

Goals

▶ Achieve reliable per-trial analysis of EEG data
▶ Confirm results of the conventional analysis
▶ Show advantages of the decoding approach
EEG: Pz Electrode

Hanke et al. (2009)
EEG: Temporal Profile

Hanke et al. (2009)
**Functional MRI (fMRI)**

<table>
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<tr>
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**Brain Activity**

- Extracellular Recordings
- Electroencephalography (EEG)
- Magnetoencephalography (MEG)
- Functional Magnetic Resonance Imaging (fMRI)
Different Levels of Decoding
Stimuli Reconstruction: Results

Miyawaki et al. (2008)
Analysis Strategies

Searchlight

- Run classifier on sphere-shaped feature clusters
- Retrieve spatial discriminance map (SDM)
- e.g. Kriegeskorte et al. (2006)
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**Classify and dissect**
- Run classifier on combinations of predefined ROIs
- Determine impact of each ROI by change in classifier error
- e.g. Pessoa & Padmala (2007)
Analysis Strategies

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Classify and dissect

► Run classifier on combinations of predefined ROIs
► Determine impact of each ROI by change in classifier error
► e.g. Pessoa & Padmala (2007)

Knockout and classify

► Transform the data using PCA projection
► Remove components and compare change in error
► e.g. Carlson et al. (2003)
Sensitivity Analysis

What is it?
- Not primarily generalization error-based
- Inspections of the ML model parameters
- e.g. Hanson et al. (2004)

Strategy
1. Preprocess the data
2. Train (fit) the model to the data
3. Ensure the validity of the model (cross-validation)
4. Extract model parameters/sensitivities and visualize them
5. Interpret the results
Hanseke et al. (2009)
Exploratory Analysis: Previous Findings

ANIMACY Discovered!

Hanson et al. (2004)
Exploratory Analysis: Multiple Areas

Hanke et al. (2009)
Unimodal Analysis: Summary

Decoding approach . . .

▶ can reliably describe the behavior in terms of neural activity
▶ can be used across different neural data modalities at different levels of investigation
▶ cares about constructing reliable estimation
▶ allows to account for cross-trial variance and covariance structure
▶ provides super-acuity effect
Multimodal Neural Data Analysis

Promises

- Finer spatio-temporal resolution
- Improved detection power
- Improved stability of the results
Multimodal Neural Data Analysis

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Difficulties

- True neural signal is not known
- Unknown model of BOLD response
- Variability of BOLD across subjects and within the brain
- EEG signal distortion
Existing Approaches

▶ Correlative analysis

▶ Seeded or preconditioned E/MEG inverse

▶ Component analyzes

▶ Bayesian inference
▶ Dynamic systems models
Existing Approaches

- Correlative analysis
  ⇒ Rigid simplistic BOLD model, mass-univariate

- Seeded or preconditioned EEG/MEG inverse
  ⇒ Bias toward fMRI analysis results, EEG/MEG inverse problem, disregard of temporal evolution of fMRI

- Component analyzes
  ⇒ Rigid simplistic BOLD model, ad-hoc components matching

- Bayesian inference

- Dynamic systems models
  ⇒ Simplifications to reduce parametrization
Methodology: EEG $\Rightarrow$ fMRI

Halchenko (2009)
Methodology: EEG $\Rightarrow$ fMRI

Halchenko (2009)
Real EEG/fMRI Data Analysis

Experiment

- Auditory experiment (Thaerig et al., 2008):
  - Mono-aural stimulation
  - 2 levels of stimulation (60 and 80 dB)
- fMRI: FLASH sequence with 147 volumes at TR=11 sec
- EEG: 29 electrodes, corrected for MR-artifacts

Goals

- Validate the suggested methodology
- Localize the areas active during the task
- Localize the areas with dominant reliance on specific EEG rhythms
Multimodal Mapping: Compare to GLM

SVR Mapping

Original:
- voxels = 7530
- range = [-0.293, 0.574]
- mean = 0.242
- median = 0.257
- std = 0.134

Thresholded: x in [0.238, +inf]:
- voxels = 4188
- range = [0.238, 0.574]
- median = 0.339
- mean = 0.331
- std = 0.0671

GLM

Original:
- voxels = 8390
- range = [-5.9, 5.68]
- mean = 0.216
- median = 0.0
- std = 1.56

Thresholded: x in [-2, 2]:
- voxels = 1794
- range = [-5.9, 5.68]
- median = 0.946
- mean = 2.25
- std = 2.59

Halchenko (2009)
Sensitivity Analysis: Spatio-Temporal Profile

Halchenko (2009)
Sensitivity Analysis: $\alpha$-band

Original:
- voxels = 7539
- range = [0.315, 0.434]
- mean = 0.367
- median = 0.366
- std = 0.0173

Thresholded: $x$ in [0.402, +inf):
- voxels = 220
- range = [0.402, 0.434]
- median = 0.409
- mean = 0.408
- std = 0.00676
Multimodal Analysis: Summary

- Validated suggested methodology on simulated and real EEG/fMRI data
- Provided localization of neural activity in the areas complementary to the results of GLM
- Provided localization for specific EEG rhythms

Additional Promises

- Interpolation of fMRI based on EEG
  - Boost of temporal resolution of fMRI
  - Improved slice-timing correction
- Filtering of fMRI and EEG
References


Welcome Michael Hanke and PyMVPA!

Thank you